UNITED STATES AIR FORCE MATERIALS TECHNOLOGY HIGHLIGHTS

AIR FORCE RESEARCH LABORATORY

Air Force Research Laboratory

Materials & Manufacturing Directorate

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Development of Advanced Aircraft Corrosion Protection for Aluminum Aircraft Surfaces

Technicians at Boeing Aerospace Support Center deliver the surface treatment to the underbody and top side of an F-15.

Scientists and engineers from the Air Force Research Laboratory's Materials and Manufacturing Directorate (ML) recently completed development of a non-chromated surface treatment for aluminum aircraft surfaces and structures. The treatment is the result of a collaborative effort between the directorate, Boeing Phantom Works and the Aging Aircraft Systems Squadron, and began operational flight tests on the KC-135 and F-15 aircraft at Hickam and Eglin Air Force Bases in late 2004.

Due to the excellent corrosion inhibiting properties of chromates, chromate-based surface treatments, primers and inhibitors have been used to control and mitigate corrosion in Air Force aircraft. However, hexavalent chrome is a known carcinogen and environmental and health regulations have designated the materials as hazardous, which requires careful handling and additional disposal expense. Though a variety of non-chromium based surface treatments have been developed and evaluated, never before has a treatment offered corrosion protection equal to the chromium-based treatments.

In 1998, the Defense Advanced Research Projects Agency (DARPA) initiated and funded an applied research program with ML's Nonstructural Materials Branch to develop a non-chromated alternative for aluminum aircraft surface treatment. The surface treatment the directorate developed, AC-131BB, uses a non-chrome, sol-gel based coating process to coat aircraft structures prior to the application of a primer and top coating. This coating system was then charted as an Advanced Technology Demonstration (ATD) and (continued on page 3)

Experts Investigate Airfield Pavements at Langley Air Force Base

A team of experts from the Air Force Research Laboratory Materials and Manufacturing Directorate's (AFRL/ML) Airfields and Pavements Group recently assessed a portion of the airfield runway at Langley AFB, Va., providing valuable support to the Air Force Civil Engineering program.

ML technicians used prototypes of recently developed ground penetrating radar (GPR) and electronic cone penetrometer (ECP) technology to determine whether voids and anomalies in the soil were causing cracks in the shoulder slab of the runway. They also investigated the integrity of the keel section of the airfield.

Electric cone pentrometer testing is conducted at Langley AFB to measure the strength and load-bearing capability of soil under the airfield pavement.

ML engineers and technicians used data collected during their investigation to determine the extent and cause of the condition and provided several nondestructive solutions to remedy abnormal or weakened portions of the runway. This field evaluation provided valuable information for further refinement of this development effort.

The ML team assessed selected airfield pavements at Langley AFB for anomalies such as voids and weakened underlying material. Langley Civil Engineering experts cited pavement surrounding a storm drainage pipe as a priority for assessment. The ML assessment included a visual inspection of the pavement, data gathering from local sources, GPR scans (both grid pattern and focused), coring and ECP testing, and data analysis and reporting.

GPR testing suggested that the soil and underlying material in the vicinity of the storm drain pipe was not adequately supporting the runway shoulder section. ML specialists concluded that the slabs were likely cracked due to a combination of loss of support from saturated soils (during previous rains, raised water table events or from leakage from the drain pipe). Their conclusions were supported by the results of ECP.

The data obtained from the GPR and ECP work concluded that an airfield closure was not needed immediately. ML experts suggested that the damage be temporarily remedied by using foam injection or grouting until an airfield closure could be scheduled to replace the damaged slabs. ML experts further recommended CE personnel at Langley AFB replace the damaged shoulder slabs by lifting (as opposed to rubblizing). They also suggested that underlying material (soil) should be examined for signs of piping, and that if the inspection shows subgrade disturbance, further excavation should be performed to visually inspect storm drain piping for possible leakage. In addition, if inspection of the shoulder slabs indicates that the keel section has been compromised, then remediation techniques, such as foam injection or grouting, should be incorporated in follow up efforts.

Scientists, engineers and technicians from ML, who are responsible for executing the AFRL pavements research program, are exploring technologies that will support rapid restoration of flying operations in the field and that will also advance Air Force technology and research efforts. This quick reaction capability provides the Civil Engineering community with innovative, timely and affordable technical assistance.

For more information, contact the Materials and Manufacturing Directorate's Technical Information and Support Center at techinfo@afrl.af.mil or (937) 255-6469. Refer to item 04-430.

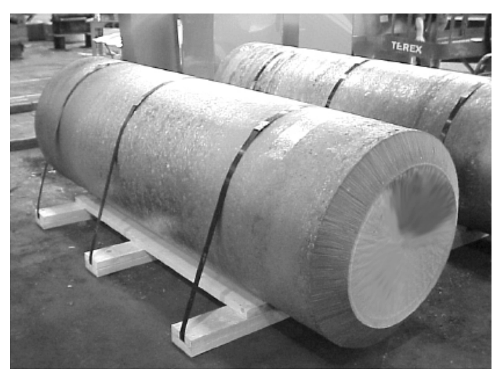
Strain-Induced Porosity (SIP) Models Improve Quality of Alloys

Scientists at the Air Force Research Laboratory Materials and Manufacturing Directorate (AFRL/ML) have developed advanced computer models for improving the processing and hence, the quality of titanium alloys used to build gas-turbine-engine parts and critical structural components for military aircraft.

These models and associated basic materials knowledge originated in the Directorate's Metals, Ceramics and Nondestructive Evaluation (NDE) Division and were transferred to titanium mill suppliers to help eliminate strain-induced porosity (SIP) or "cavitation" in billet products and finished parts. Cavitation is a serious concern in hot working of materials because it can lead to premature failure during forming and also give rise to inferior properties in the final parts.

Titanium (Ti) is a very durable, low-density element approximately 60 percent the density of iron that can be significantly strengthened by alloying and deformation processing. Ti alloys have been used as a replacement for iron and nickel alloys in aerospace applications for many years because they reduce weight and operate very well at low to moderately elevated temperatures.

Ti and Ti alloys are used in two principal application areas: corrosion-resistant service and low weight, high specific strength structures. Rotating components in aircraft gas turbine engines, such as turbine disks and blades, belong to the second category, and require Ti alloys that maximize strength-to-weight ratio and metallurgical integrity/reliability at service temperatures. These alloys must exhibit good fatigue resistance and low creep rates. User requirements are very stringent to ensure controlled homogeneous microstructures and freedom from imperfections whose source is melting-related (such as alloy segregation, high or low-density inclusions, and ingot porosity or pipe) or thermomechanical-processing-related (such as SIP, shear bands, and undesirable residual stresses). Ti-6Al-4V, Ti-6Al-2Sn-4Zr-2Mo, Ti-5Al-2Sn-2Zr-4Mo-4Cr, and Ti-6Al-2Sn-4Zr-6Mo are examples of common titanium alloys currently in use.



ML has designed ingot conversion practices to avoid strain-induced porosity (SIP) defects and to improve the quality of billet stock used during the part forging process and hence, finished components.

In metallic materials, SIP is defined as the (undesirable) formation of cavities during hot working. The cavities usually nucleate at grain boundaries (the boundaries between the crystals that form the material) as a result of local stresses and strains induced by sliding along the boundaries at hot-working temperatures. Depending on the precise state of stress and strain, the cavities may grow to various sizes (i.e., from nanometers to micrometers in size), and in extreme cases, lead to gross fracture. Internal, micrometer-scale cavities are very difficult to detect using non-destructive techniques. Nonetheless, because of the deleterious effect of SIP on subsequent processing (i.e., superplastic forming) and/or service, it is very important to avoid the formation and growth of cavities during hot working.

The modeling of cavitation (and failure) during hot working of ductile metals by ML researchers has focused on three different types of approaches: phenomenological, mesoscale mechanistic, and microscale mechanistic. Phenomenological approaches, which have had immediate near-term application in industry, seek to relate the occurrence of damage and gross fracture in complex stress states to measurements made under a simple stress state, such as uniaxial tension. By contrast, mesoscale mechanistic models, which have near-to-medium-term application, treat the plastic growth of individual cavities and their coalescence. Reasonable estimates of hot ductility can be obtained from mesoscale techniques in spite of the need to make assumptions regarding cavity nucleation. Fundamental, microscale mechanistic models describe the mechanisms of the early stages of cavity growth in an attempt to provide a basis for quantifying nucleation-type behavior. These last approaches have long-term potential for the design of novel manufacturing processes.

Scientists in ML's Metals, Ceramics and Nondestructive Evaluation (NDE) Division began working on cavitation models in 1997. The result of their work was the successful development of the phenomenological and mechanistic models. The phenomenological and mesoscale mechanistic models have been transferred to Ti mill suppliers, who are using them to modify and improve their production practices.

Successful transfer of ML's models to mill suppliers improves the quality of gas turbine engine and aircraft parts by reducing

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Technicians at Boeing Aerospace Support Center apply alodine 600, part of the new surface treatment to the KC-135.

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the Aging Aircraft Systems Squadron (ASC/AASS) initiated funding to demonstrate this technology on operational aircraft.

To date, aluminum test panels prepared using the new treatment have completed 1,000 hours of salt spray testing, and will continue the testing until coating failure, to determine whether the treatment performs well. In addition, the directorate has performed filiform and adhesion testing, with all panels meeting the appropriate requirements.

KC-135 and F-15 aircraft were chosen to represent transport and tactical aircraft, respectively, during operational flight testing of the non-chromated surface treatment. These systems were selected because the production environment for these aircraft is very different. Access to treat, coat or paint the F-15 can be made from the hanger floor or from the top of the aircraft while the KC-135 has much more difficult access that requires special lifts. The F-15 has several sharp contours and offers access to hatches on the exterior surface. Contours on the KC-135 aircraft are more gradual with few completely horizontal surfaces, which makes drainage of the process solution from the aircraft easier than with the F-15.

AC-131BB was applied to one side of each aircraft using conventional painting equipment after masking of the aircraft navigation lights, some weapon attachment points, engine surfaces, etc. The other half of the aircraft was treated in the normal fashion with a chromated surface treatment for comparison during the test. The normal primer and topcoat were then applied to both sides. A crew of three workers was able to apply the coating to the right side of the F-15 in around 25 minutes, which included practice on a test panel and discussion of application techniques. Following application of the treatment to both aircraft, the solution was allowed to drain and drips and drainage were removed. The treatment was applied and the surfaces were painted at Boeing Aerospace Support Center and Robins AFB.

Plans for the second phase of the program include monitoring the performance of the coating systems, and addressing lessons learned during the application of the treatment. The aircraft will be examined every four months for evidence of corrosion or coating failure. The ultimate goals of monitoring the operational test aircraft are to assess the performance of the coating, allow comparison with laboratory data, evolve the technology and optimize application procedures and overall performance.

Development of an environmentally safe, non-chromated surface treatment for aluminum aircraft structures is one of several Air Force initiatives concerned with providing aircraft with advanced corrosion protection that is increasingly environmental friendly. Replacing existing chromate containing treatments is expected to eliminate 90 percent of the Air Force's hazardous waste stream and to reduce costs associated with handling and disposal of the current chrome-based treatments, which are carcinogenic. Feedback provided by maintenance depots during the second phase of the program is expected to improve the efficiency of the treatment application process, optimize the treatment for vehicle and depot specific issues, and provide new concepts in the way new non-chromate materials perform against the current and proposed performance requirements of aircraft systems.

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cavitation. This new technology will help suppliers build quality into the manufacturing process, and thus reduce the need to inspect for problems later. The ML models will also increase product yield and therefore reduce the amount of scrap material, which will help lower production costs. Quality improvements in titanium and titanium alloys will also benefit commercial aircraft manufacturing and other key industries.

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